THE CORRECTION TECHNIQUE FOR IRI MODEL ON THE BASIS OF OBLIQUE SOUNDING DATA AND SIMULATION OF IONOSPHERE DISTURBANCE PARAMETERS

A.G. Kim(1), **Z.F. Dumbrava**(2), **V.P. Grozov**(3), **G.V. Kotovich**(4), **Y.S. Mikhaylov**(5), **A.V. Oinats**(6)

(1)Institute of Solar-Terrestrial Physics SB RAS, P.O.B. 4026, Irkutsk, 664033, Russia, e-mail: kim_anton@mail.ru

(2)Institute of Cosmophysical Research and Radio Propagation FEB RAS, 684034, Kamchatka region,

Elizovskiy district, Paratunka, Mirnaya st., 7, Russia, e-mail: ikir@ikir.kamchatka.ru

(3)As (1) above but e-mail: grozov@iszf.irk.ru

(4)As (1) above but e-mail: kotovich@fromru.com

(5)As (1) above but e-mail: mikhaylov@iszf.irk.ru

(6)As (1) above but e-mail: oinats@iszf.irk.ru

ABSTRACT

New way of IRI model adaptation to ionosphere conditions on the basis of oblique sounding (OS) experimental data obtained by chirp-sounder was used. This correcting technique can be applied to other f_0F2-adaptable models of the ionosphere. The IRI adaptation was made by means F2-layer critical frequency correction at middle point of the path. Value of the critical frequency was got from the distance-frequency characteristic (DFC) by converting “last point” of upper ray by means improved Smith’s method. The some anomalous OS ionograms, which were registered in experiments during March 2004 on Magadan—Irkutsk and Khabarovsk—Irkutsk paths, are shown. The technique for modeling of oblique sounding anomalous DFC on the basis of joint using of OS and vertical sounding experimental data, IRI model and method of characteristics are presented. The results are of interest for problems of OS-data based operational diagnosis and prediction, particularly vital for areas where vertical sounding data are lacking or unavailable.

INTRODUCTION

Forecasting propagation conditions for high frequency radio waves relies on various models of the ionosphere, the IRI (International Reference Ionosphere) model being regarded as the most promising and widespread of them. But models are primarily oriented towards the average unperturbed state of the ionosphere and, even under quiet geomagnetic conditions, often require adjusting. Operational predictions require a combined application of the model ionosphere, experimental data and techniques for computing radio wave propagation characteristics. Using experimental data from oblique sounding (OS) necessitates the examination of factors responsible for distorting both the distance-frequency characteristic (DFC) and the 24-hour variation of maximum observed frequencies (MOF).

This paper used experimental chirp-sounder data obtained on two OS paths [1] during the 29 March to 2 April 2004 observing period, witnessing an almost simultaneous operation of transmitters in Magadan (60°N, 150.7°E) and Khabarovsk (48.5°N, 135.1°E). The observing interval for each path was 15 min. The receiving station at the village of Tory (51.8°N, 103°E) is 100 km away from Irkutsk (52°N, 104°E). The Khabarovsk—Tory path is 2297 km, Magadan—Tory 3034 km long. Both are one-hop paths, the distance between the Khabarovsk—Tory (51.26°N, 119.57°E) and Magadan—Tory (58.2°N, 124.17°E) path's midpoints being 825 km.

Fig.1 shows several anomalous OS ionograms with traces of travelling ionospheric disturbances (TIDs). "Anomalous" refers to DFCs uncharacteristic of a spherically-layered ionosphere or an ionosphere with a weak horizontal gradient. To analyse these data, the computations relied on the IRI model in both the long-term prediction and adaptation mode. The maximum usable frequencies (MUFs) were computed using a complex algorithm [2], based on the normal waves method, while DFCs were modelled using the method of characteristics [3].

THE CORRECTION TECHNIQUE

The magnetic data implied that the activity index Kp was, on average, never above 3 over the experimental observation period. However, 30 March saw the distribution of the local three-hour K-index in Irkutsk (3, 3, 2, 4, 4, 2, 2, 3) demonstrating a small disturbance in the Earth magnetic field (EMF). Even though the EMF was quiet on the other days, one could observe, at some time moments, fairly persistent distortions in DFC in OS ionograms, ostensible as inflections, loops and dispersion in the upper ray area (Fig.1).

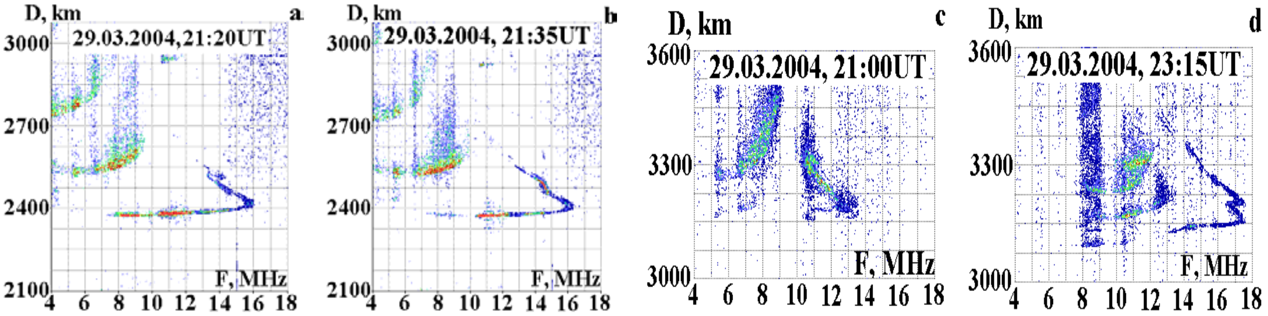

Fig. 1. Some anomalous OS ionograms, Khabarovsk—Tory (a, b) and Magadan—Tory (c, d).

The OS ionograms were processed in semi-automatic mode. A MOF array was formed in the process, while also saving the signal's absolute propagation time and frequency for the "last point" (Fig.2b) in the upper ordinary 1F2-mode ray (whose pre-reflected trajectory is close to a Pedersen ray passing at the height of ionisation maximum in the vicinity of the path's midpoint). These were used to calculate, using modified Smith's method [4], the critical frequency f_0F2 at the path's midpoint by means of the algorithm in [5]. Afterwards, the values obtained with the IRI model were adapted given the f_0F2 from vertical sounding (VS) data at the path's endpoints and the computed f_0F2 values at the path's midpoint (f_0F2 values between these three points along the path were linearly interpolated). The algorithm for recalculating OS data allows the height-frequency characteristic (HFC) to be obtained at the path's midpoint, but in order to adjust the model one needs only to know f_0F2 (Fig.2c).

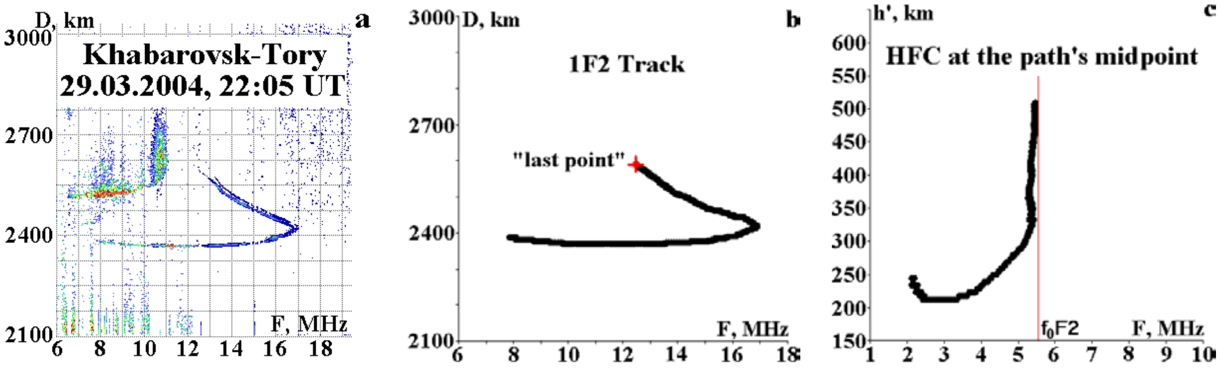

Fig. 2. From DFC to f_0F2 at the path's midpoint.

The f_0F2 computation results were compared to the IRI model, demonstrating the behaviour of the re-calculated values to be adequate to those predicted. The check whether the long-term MUF predictions based on experimental OS data can be made more precise by correcting the f_0F2, has shown good consistence between the corrected MUF and the experimental MOF values. The use of MUF calculations enables MOF to be predicted or restored based on the "last point" if its value has transgressed the operating frequency band.

The characteristic variability of the 24-hour MOF curves at two neighbouring paths enables one to judge about the presence of a moving medium-scale irregularity in the F2-layer maximum region. The maximum in the 24-hour MOF variation in the paths analysed were time-shifted on 30 March to 1 April 2004. Knowing the distance between the path's midpoints and their coordinates has enabled the irregularity's speed and travel direction to be estimated. The disturbance appears to be positive in character, and a MOF increase first observable on the Khabarovsk—Tory and, later, the Magadan—Tory path, proves that the irregularity was moving south to north. The time delay between the disturbance manifestations shows that its travelling speed was 70-100 m/s.

SIMULATION

The studies of irregularities in the ionosphere, including the TIDs, are of much scientific and applied importance, and, not surprisingly, this issue has been dealt with in a multitude of papers, e.g. [6-8]. They show that, along with diurnal and seasonal variations in ionospheric parameters (large-scale irregularities), the ionospheric heights always witness the presence of travelling ionised structures of a small to medium scale.

An attempt to interpret such types of OS ionograms (Fig.1) was described in [9]. The simulation concerned the Khabarovsk—Tory path, within the framework of a one-layer parabolic model of the ionosphere. Experimental VS data for the transmitting and receiving stations were employed. Ionospheric parameters at the path's midpoint were estimated by recalculating the experimental DFC into HFC [10]. With the upper ray forming at altitudes close to the F2-layer maximum [11], distortion in this ray (Fig.1) testifies to TIDs being most likely to be found at the same level. In Khabarovsk, h_mF2 varied 290 to 300 km, in Irkutsk 300 to 320 km, therefore the simulation employed a linear h_mF2 variation along the (transmitter-to-receiver) path of 295 to 310 km. A 15-km rise of the height of an F2-layer electron concentration maximum's simulated disturbance from the middle of its unperturbed course corresponds to an altitude of 315 km (Fig.3a). A triangular disturbance with a ~330 km-wide base was simulated.

The empty circles in Fig.3b represent the DFC calculated for 29 March 21:00 UT and a mean monthly index F10.7 = 111 (medium parameters were set based on the IRI model without adjusting). The MUF calculated by the normal waves method and the method of characteristics (based on the IRI model, without adjustment), corresponds to 10 MHz. One can see that the experiment MOF (crosses) is 5.5 MHz above the calculated MUF at this hour. Filled circles show the calculated DFC after adapting the IRI model with regard to the critical frequencies at three points in the path (using linear interpolation along the path). In this case, the divergence of the obtained MUF from the MOF observed in the experiment was a mere 2%.

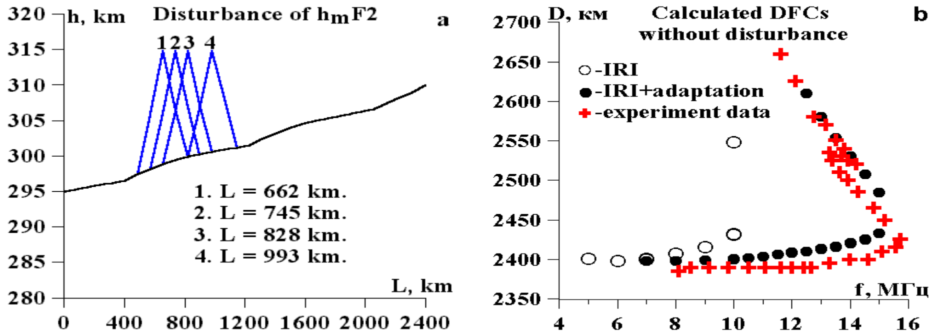

Fig. 3. The modeling disturbance of h_mF2 (a). The computed DFCs without h_mF2 disturbance and experiment data (b).

Fig.4 displays the simulated anomalous DFCs with a horizontally moving disturbance of the h_mF2 (Fig.3a), at distances of 662, 745, 828 and 993 km from the transmitter, along the (transmitter-to-receiver) path. In the event of such a disturbance travelling over greater distances, no considerable changes are observed in the upper ray in the computed DFC. The calculations involved the IRI model (in adaptation mode) and the method of characteristics [12].

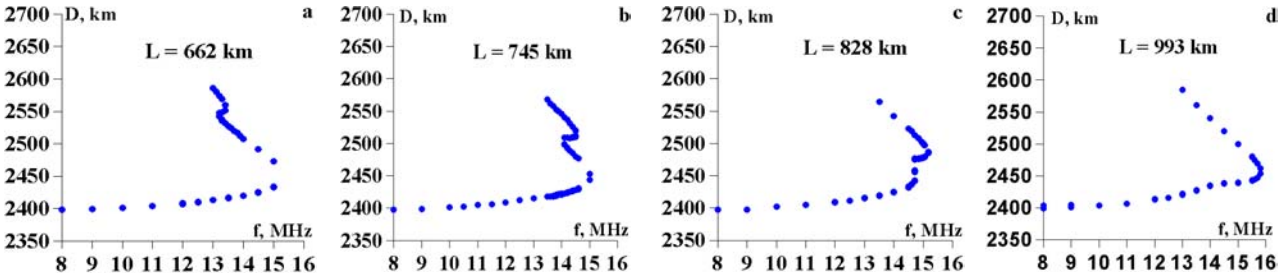

Fig. 4. The computed DFC with h_mF2 disturbance at the different distances from the transmitter.

When the disturbance approaches the path's midpoint, the MUF increases, as demonstrated in Fig.4d. With characteristic TID speeds of ~100 m/sec, the inflection travel dynamics along the upper ray enables one to judge on the TIDs' existence times and sizes. In the experiments we conducted, the duration of the existence of such distortions varied 15 min to a few hours. This corresponds to horizontal sizes of TIDs of ~90 km, registered within a space of ~1000 km. The minimum distance of 90 km was due to the registration interval. In fact, the size of such an irregularity may be even smaller than 90 km, because the upper ray's deformation during a session can be registered only in isolated DFCs.

CONCLUSION

This paper applied a technique to adapt the IRI model to ionospheric conditions based on experimental OS data. This correcting technique can be applied to other f_0F2-adaptable models of the ionosphere. A necessary condition is the presence of reliable (time-referenced) experimental OS data and the possibility to obtain the parameters (time delay, frequency value) of the 1F2 mode upper ray.

A disturbance model was verified representing a certain h_mF2 behavioural pattern in the OS path's local areas. Simulation has demonstrated that anomalous DFC records with 1F2-mode upper ray inflections characteristic of TIDs can be explained by the presence of small horizontal variations in h_mF2 (with disturbance sizes of ~20 km high, ~300 km long) and by their movement along the signal propagation path at a distance of 650-900 km from the transmitter (for a ~2300 km-long path). Observations on 29 March to 2 April 2004 registered TIDs lasting 15 min to a few hours. Analysis of the 24-hour MOF variation in two neighbouring (latitudinally directed) OS paths, in the period 30 March to 1 April 2004, has shown that the hours of maximum MOF (~06:00 UT) on these days saw an ionospheric disturbance travelling at a speed of 70-100 m/s from south to north, that existed at a distance of at least ~1000 km.

The technique we propose for quickly re-calculating OS data into the critical frequency (HFC can be computed in the same way) at the path's midpoint allow for swiftly adapting the ionospheric model (for a territory covered by the OS path) to experimental OS data.

The results are of interest for problems of OS-data based operational diagnosis and prediction, particularly vital for areas where VS data are lacking or unavailable.

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